PAPR REDUCTION METHOD USING BIT REALLOCATION

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a peak to average power ratio

5   (PAPR) reduction method and, more particularly, to a peak to average

power ratio (PAPR) reduction method using bit reallocation, adapted for

fields including a multi-carrier system or an orthogonal frequency division

multiplexing (OFDM) system and the like.

2. Description of Related Art

10   In recent years, because a multi-carrier system, such as an OFDM

system, can overcome multi-path interference and also increase spectral

efficiency without using complicated transmitters and receivers, it is widely

applied in many communication systems such as ADSL, DAB, DVB,

WLAN (IEEE 802.11a, HiperLAN/2), WMAN (IEEE 802.16a) and the

15   like.

A bit loading technique is typically used to increase the capacity of a

multi-carrier system. Namely, after power allocation for transmissions at

different sub-carriers (sub-channels) is determined, the transmissible

information (i.e., the number of bits) and a mechanism of corresponding

20   signal constellations at different sub-carriers are determined. FIG. 1 is a

graph illustrating a typical Water-filling technique used for power

allocation to achieve channel capacity and best spectral efficiency in a

frequency selective channel. As shown in FIG. 1, for an AWGN channel, its

frequency response is constant at all sub-carriers. Thus, information carried

at each sub-carrier is allocated with same power to achieve channel capacity. However, for a multi-path frequency selective fading channel or any time varying channel, the channel capacity may not be achieved by the cited constant power allocation. Accordingly, a Water-filling technique is applied for transmissions over these channels.

As shown in FIG. 1, the frequency response of a frequency selective channel is divided into N frequency segments. The frequency response of each segment can be regarded to be constant for a multi-carrier system. Furthermore, in a multi-carrier system, one sub-carrier carries information over one frequency segment. If the frequency response is $h_1, h_2, \cdots, h_N$ respectively at the N sub-carriers and the power spectrum density (PSD) of noise is $\sigma_1^2, \sigma_2^2, \cdots \sigma_N^2$ respectively in the N sub-carriers, the channel signal to noise ratio (CNR) can be defined as:

$$\gamma_i = \frac{|h_i|^2}{\sigma_i^2}, \quad i = 1, 2, \cdots, N.$$

For a $\dfrac{1}{\gamma_i}$ to frequency graph as shown in FIG. 1, assumed that water is injected into along the curve, the amount of water at the peak of the curve is less than that at the valleys. At this point, the amount of water represents the transmission power P_i at each sub-carrier to be allocated.

After power allocation for transmissions at all sub-carriers is determined, a bit loading technique is applied to determine the transmissible number of bits at different sub-carriers. FIG. 2 shows a schematic diagram of functional blocks of a transmitting end in which an

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adaptive bit loading technique is applied. In FIG. 2, the transmitting end includes an adaptive constellation mapping unit 11, an adaptive bit loading unit 12, a serial to parallel (S/P) unit 13, an inverse fast Fourier transform (IFFT) unit 14, and a parallel to serial (P/S) unit 15. As shown in FIG. 2, the

5   number of bits carried at different sub-carriers can be adjusted in dynamic against a time varying channel. Let B be the system transmission bandwidth, Δf be the frequency difference between any two adjacent sub-carriers and N be the number of sub-carriers, thus

$$B = N * \Delta f.$$

10   The total transmission power P for the system can be computed by the equation of:

$$P = \sum_{i=1}^{N} P_i,$$

where P_i is the transmission power at the i-th sub-carrier and $1 \leq i \leq N$. In addition, the total number of bits R per signal block transmitted by the

15   system with transmission bandwidth B is:

$$R = \sum_{i=1}^{N} R_i,$$

where R_i is the number of bits per signal block carried by the i-th sub-carrier. Given conditions upon channel features (channel frequency response and frequency spectrum density of noise), power allocation,

20   modulated signaling (such as QAM, the Quadrature Amplitude Modulation), bit error rate (BER) requirement, and power margin , the

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maximum number of bits R_i per signal block transmissible by the i-th sub-carrier can be computed by the well-known equation [ref] of:

$$R_i = \log_2\left(1 + \frac{P_i\gamma_i}{\gamma_m\gamma_b}\right),$$

where γ_m is the power margin for overcoming abrupt attenuation or additional noise appearing at the sub-carriers of a time varying channel and γ_b is the "SNR gap" in the well-known "gap approximation"[ref]. For example, $\gamma_b = 9dB$ if a theoretical limit bit error rate $\varepsilon = 10^{-7}$.

To maximize the total number of transmission bits, D, of one signal block in a multi-carrier system without violating the system constraint of maximal transmission power P_{max}, the mathematical expressions are given below:

$$\max\left\{\sum_0^{N-1}d_i = D\right\}$$
$$\text{subject to} \left\{\sum_0^{N-1}P_i \leq P_{max}\right\}.$$

As cited, Campello's first bit loading algorithm could be applied in the prior art to achieve the purpose. Let $P_i(d_i)$ represent the transmission power allocated at the i-th sub-carrier with d_i bits, Δd represent the number of bit increment of one adjustment (for example, in the Campello's first algorithm, $\Delta d = 1$) for bit loading, and $\Delta P_i(d_i)$ represent the power increment required for increasing the number of transmission bits from $(d_i - \Delta d)$ to d_i. Then, $\Delta P_i(d_i)$ can be represented by the following equation,

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$$\Delta P_i(d_i) = \begin{cases} P_i(d_i) - P_i(d_i - \Delta d) & \text{if} \quad d_i \geq \Delta d \\ P_i(d_i) - P_i(0) & \text{if} \quad d_i < \Delta d \end{cases}.$$

The cited bit allocation at each sub-carrier is not adjusted until both the following conditions are met:

Condition 1: $\Delta P_i(d_i) < \Delta P_j(d_j + \Delta d)$, $\forall i, j \in \{1, 2, \cdots, N\}$, and

5   Condition 2: $0 \leq P_{max} - \sum_{i=1}^{N} P_i(d_i) < \min_j \Delta P_j(d_j + \Delta d)$.

In fact, the aforementioned purpose can also be achieved by means of any bit loading algorithm in a multi-carrier system.

However, a high peak to average power ratio (PAPR) possibly occurs not only before applying any bit loading algorithm but also after

10   doing that, . An OFDM system or a multi-carrier system with high PAPR usually incurs incremental complexity and reduced efficiency on the application of an analog-to-digital converter (ADC), digital-to-analog converter (DAC), power amplifier (PA) or line driver (LD).

Therefore, it is desirable to provide an improved PAPR reduction

15   method to mitigate and/or obviate the aforementioned problems.

SUMMARY OF THE INVENTION

The objective of the present invention is to provide a peak to average power ratio (PAPR) reduction method using bit reallocation, such that the probability of PAPR larger than a predetermined value does not

20   exceed a predetermined probability, thereby concurrently having low power and low PAPR.

To achieve the objective, the inventive PAPR reduction method is

applied to a multi-carrier system, which transmits signal blocks, each of which consists of D-bit data, through N sub-carriers over a channel. The channel is with N frequency segments corresponding to the N sub-carriers. The inventive PAPR reduction method includes an initializing step, a PAPR

5   computing step, a comparing step and an adjusting step. In the initializing step, a bit loading algorithm is initialized to allocate the number of bits at each sub-carrier for efficient data transmission. In the PAPR computing step, the PAPR for the transmission of one signal block in the multi-carrier system is computed according to number of bits and also the modulation of

10   these bits at the sub-carriers. When the PAPR is larger than a predetermined value (the comparing step), the adjusting step is performed by increasing Δd bits in the transmission at a first selected sub-carrier and decreasing Δd bits in the transmission at a second selected sub-carrier . Next, the PAPR computing step is performed again, wherein the PAPR computing step to

15   the adjusting step are not repeated until the PAPR is less than the predetermined value or until a predetermined maximal number of iteration is reached.

      Other objectives, advantages, and novel features of the invention will become more apparent from the following detailed description when

20   taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

      FIG. 1 is a graph illustrating a typical Water-filling technique used for power allocation to achieve channel capacity and best spectral efficiency in a frequency selective channel;

FIG. 2 shows a schematic diagram of functional blocks of a transmitting end with a typical adaptive bit loading algorithm;

FIG. 3 is a block diagram of a PAPR reduction method using bit reallocation according to an embodiment of the present invention;

FIG. 4 is a flowchart of a PAPR reduction method using bit reallocation according to the embodiment of the present invention;

FIG. 5 is a flowchart of step S401 of FIG. 4 according to the embodiment of the present invention;

FIG. 6 is a flowchart of an example step S405 of FIG. 4 according to the embodiment of the present invention; and

FIG. 7 is a flowchart of another example step S405 of FIG. 4 according to the embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

With reference to FIG. 3, there is shown an embodiment of functional blocks of a multi-carrier system 3 (for example, an orthogonal frequency division multiplexing (OFDM) system). In FIG. 3, the system 3 includes an adaptive constellation mapping unit 31, an adaptive bit loading and PAPR (peak to average power ratio) reduction unit 32, a side information protector 33, a serial to parallel (S/P) unit 34, a parallel to serial (P/S) unit 35, an inverse fast Fourier transform (IFFT) unit 36, a fast Fourier transform (FFT) unit 37and an adaptive constellation demapping unit 39. The cited devices, which can easily be implemented by a person in the art except for the unit 32 and the protector 33, will not be described in detail. In the following description, unit 32 essentially performs bit reallocation at the

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sub-carriers for reducing PAPR and protector 33 essentially protects the side information due to bit reallocation.

FIG. 4 is a flowchart of a PAPR reduction method using bit reallocation according to the embodiment of the invention. The transmitter of system 3 transmits data through N sub-carriers over a channel 38 which is with N frequency segments corresponding to the N sub-carriers. Accordingly, as shown in FIG. 4, a bit loading algorithm is initialized to allocate d_i bits at each sub-carrier for transmission of one signal block (step S401), where $0 \le i \le (N-1)$. In this embodiment, assume that the total number of bits of transmitting one signal block be D bits , the goal to achieve the lowest total transmission power of the system can be mathematically expressed as follows:

$$\min \left\{ \sum_0^{N-1} P_i \right\}$$

$$\text{subject to} \left\{ \sum_0^{N-1} d_i = D \right\}.$$

With reference to FIG. 4 and also FIG. 5, a flowchart of an initializing step S401 of FIG. 5 is described in detail. In FIG. 5, the initializing step applies a bit loading algorithm to allocate the number of bits at each sub-carrier. In this embodiment, Campello's second bit loading algorithm is not applied to adjust bit allocation at each sub-carrier until the following condition (same Condition 1 as in the prior art) is met:

Condition 1: $\Delta P_i(d_i) < \Delta P_j(d_j + \Delta d)$, $\forall i, j \in \{1,2,\cdots,N\}$.

Note that other bit loading algorithm can also be applied to our inventive PAPR reduction method. One possible process to execute

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Campello's second algorithm is shown in FIG.5. As shown in the first block of FIG. 5, each sub-carrier is at first equally allocated with same number of bits, i.e. $d_i = D/N$ where $0 \le i \le (N-1)$ (step S501). In the second block, by comparing the power increment at all sub-carriers, each of which is increased by Δd-bit (such as 1-bit, 2-bit,..., etc.) , an m-th sub-carrier with the smallest power increment, ΔP_m , among all sub-carriers is selected , where $m = \arg[\min_{0 \le i \le N-1} \Delta P_i (d_i + \Delta d_i)]$ (step S502). In the third block, by comparing the power decrement at all sub-carriers, each of which is decreased by Δd-bit , an n-th sub-carrier with the largest power decrement, ΔP_n ,among all sub-carriers is selected , where $n = \arg[\max_{0 \le i \le N-1} \Delta P_i (d_i)]$ (step S503). It is noted that the steps S502 and S503 can be exchanged or merged into one step. To achieve the lowest total transmission power with the constraint of total D transmitted bits per signal block, the power increment, ΔP_m, at the m-th sub-carrier which carries more Δd-bit is compared to the power decrement, ΔP_n, at the n-th sub-carrier which carries less Δd-bit in the fourth block (step S504). Then, an adjusting operation that more Δd-bit is increased at the m-th sub-carrier and decreased at the n-th sub-carrier is performed in the fifth block (step S505). Steps S504 and S505 can be explained in more detail as follows.

When $\Delta P_m(d_m + \Delta d) < \Delta P_n(d_n), \forall m, n \in \{1, 2, \cdots, N\}$, the following steps are performed:

$d_m = d_m + \Delta d$, and

$d_n = d_n - \Delta d$.

On the contrary, when $\Delta P_m(d_m + \Delta d) \ge \Delta P_n(d_n), \forall m, n \in \{1, 2, \cdots, N\}$,

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the total transmission power can not be reduced anymore , the process is over.

After determining the carrying data d_i at the i-th sub-carriers by the bit loading algorithm , an IFFT operation is used to compute the PAPR of the transmission of one signal block in the multi-carrier system 3 (step S402). The PAPR may still be large even that the smallest total transmission power is reached. To avoid this circumstance, the following operations are performed. When the PAPR of the transmission is larger than a predetermined value A (e.g. 6dB)(step S403), the bit reallocation is performed to reduce the PAPR such that the PAPR is not larger than A . Accordingly, the mathematical expressions to achieve the lowest total transmission power P are modified as follows:

$$\min\left\{\sum_0^{N-1} P_i\right\}$$

$$\text{subject to} \begin{cases} \text{PAPR} \le A \cdot \\ \sum_0^{N-1} d_i = D \end{cases}$$

Namely, if the PAPR of the transmission of one signal block after being processed by the initial bit loading algorithm is large, the signal block needs to perform bit reallocation operation in order to reduce the PAPR. Continuing the bit allocation operation of the bit loading algorithm even when the constraint, $\Delta P_m(d_m + \Delta d) \ge \Delta P_n(d_n), \forall m, n \in \{1,2,\cdots,N\}$, is reached is one possible bit reallocation solution. That is, Δd bits are increased to a selected sub-carrier and decreased to another selected sub-carrier (step S405) in similar bit allocation operations (steps S502, S503, S505, ignoring step S504), thereby maintaining the entire

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multi-carrier system 3 in a fixed transmission rate. The selection is still according to the power incremental/decremental equation:

$$\Delta P_i(d_i) = \begin{cases} P_i(d_i) - P_i(d_i - \Delta d) & \text{if} \quad d_i \geq \Delta d \\ P_i(d_i) - P_i(0) & \text{if} \quad d_i < \Delta d \end{cases}.$$

The operations are not executed until a predetermined maximal iteration number L is reached (step S404). The cited step S405 is defined as one adjustment. After one adjustment is complete and thus a new bit allocation at each sub-carrier is generated, the PAPR is re-computed in accordance with the new bit allocation at each sub-carrier (step S402). Then, comparing the re-computed PAPR to the predetermined value A and accordingly determining if the re-computed PAPR meets with the system constraint (step S403). If the answer is "yes", the process is over. The cited PAPR comparison is not performed until the number of adjustment exceeds the predetermined maximal iteration number L (step S404). The predetermined maximal number of iteration L is defined for the purpose of reducing system load. For example, if the largest number of adjustment is T for the multi-carrier system using N sub-carriers, the operation ends after at most L adjustment number is performed, even if the PAPR cannot meet with the system constraint.

With reference to the flow chart of FIG.5 and that of FIG. 6, steps S502, S503 and steps S601, S602 fully search around all sub-carriers for the bit reallocation operation. Similar to steps S502, S503 of FIG. 5, in steps S601, S602 of FIG. 6, by comparing the power increment at all sub-carriers, each of which is increased by Δd bits, an x-th sub-carrier with the smallest

power increment ΔP_x among all sub-carriers is selected, wherein $x = \arg[\min_{0 \le i \le N-1} \Delta P_i (d_i + \Delta d_i)]$ (step S601). By comparing the power decrement at all sub-carriers, each of which is decreased by Δd bits, a y-th sub-carrier with the largest power decrement ΔP_y decreasing among all sub-carriers is selected, wherein $y = \arg[\max_{0 \le i \le N-1} \Delta P_i (d_i)]$ (step S602). Then Δd -bit carrying data is increased at the x-th sub-carrier and decreased at the y-th sub-carrier (step S603). The cited steps S601 and S602 can be exchanged in operation or merged into one step.

FIG. 7 shows a flow chart of another preferred search process for step S405. As shown in the first block of FIG. 7, the individually incremental power required for increasing Δd -bit transmission at each sub-carrier is sorted from small to large. The first smallest M incremental power for transmission at the M sub-carriers is selected (stepS701), where $M \le N$. On the other hand, as shown in the second block of FIG. 7, the individually decremental power required for decreasing Δd -bit transmission is sorted from large to small. The first largest M decremental power at the M sub-carriers is selected (stepS702). The Δd -bit increment/decrement at these selected sub-carriers are sequentially applied to one adjustment (stepS703).

In practice, the system constraint for bit error rates at different sub-carriers can be set to $\varepsilon_1 = \varepsilon_2 = \cdots = \varepsilon_N = \varepsilon$, or looser. Namely, power allocation is adjusted by the following equation according to the constraint of bit error rates at different sub-carriers.

$$R_i = \log_2\left(1 + \frac{P_i \gamma_i}{\gamma_m \gamma_b}\right).$$

After bit reallocation is complete, the number of bits carried at each sub-carrier is possibly changed. As such, the multi-carrier system 3 needs additional information delivery, i.e., side information. In this embodiment,

5   the side information protector 33 is fed back to the adaptive constellation mapping unit 31 or delivered over an additional channel 38'. Efficient error correction code can be applied to protect the side information.

As cited, the inventive method applies bit loading and bit reallocation techniques to effectively reduce PAPR and concurrently obtain

10   a low power target.

Although the present invention has been explained in relation to its preferred embodiment, it is to be understood that many other possible modifications and variations can be made without departing from the spirit and scope of the invention as hereinafter claimed.

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